Calibration of Precipitation Forecast

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EMC ensemble and post process team
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Acknowledgments:
NCEP: Mike Charles, Dingchen Hou, Bo Cui, Ying Lin, Jun Du
Geoff DiMego, John Ward, Bill Lapenta and Stephen Lord
And
ESRL: Paul Schultz, Huiling Yuan and Zoltan Toth
OHD: Dong-Jun Seo

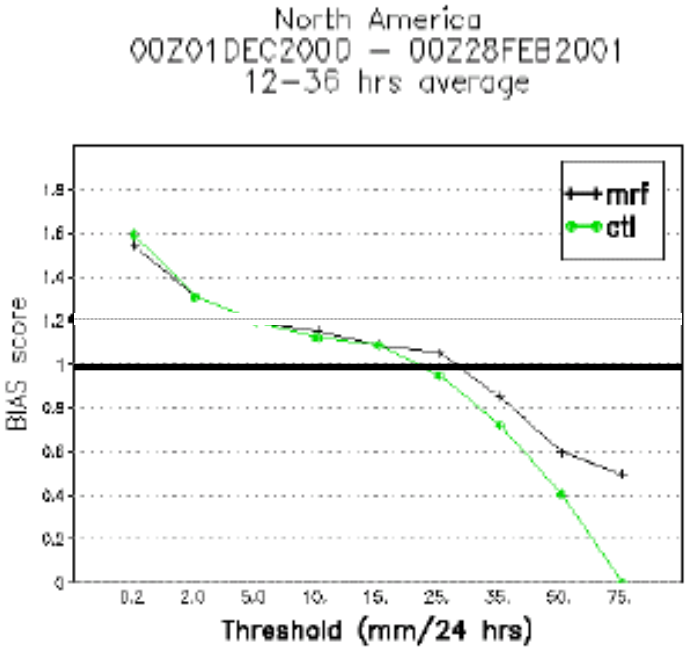
EMC Plans (FY10-FY11)

1. Background (QPF bias correction in NCEP)
   - Implemented May 2004 (HPC, CPC endorsed)
   - Bias corrected GFS/GEFS forecasts
     - At 2.5 degree resolution, every 24 hours, using Gauge (12UTC-12UTC)
     - Using decay average (or Kalman Filter) method for sampling
     - Using frequency match algorithm for CDF of OBS/FCST
2. Climatological Calibrated Precipitation Analysis (CCPA) – Q2FY10
   - Use 30year CPC unified analysis at 1/8 degree, daily, global land - reliability
   - Use 8year NCEP Stage IV (mosaicked QPE from RFCs), 4km HRAP grid, 6-h (ConUS) – resolution
   - Use regression method to generate a and b from above two datasets
   - Produce CCPA analysis (CCPA = $a*QPE_{rfc} + b$)
   - Resolution is 5km (NDFD) grid (and subsets) for CONUS
3. Update QPF bias correction from #1 – Q2FY10
   - Bias corrected GFS/GEFS forecasts at 1.0 degree and 6 hours
   - Bias corrected NAM/SREF forecasts at 30km and 1 hours (optional)
4. Statistical downscaling to 5km - Q4 FY10
   - Proxy of truth - CCPA at NDFD grid (5km) or RTMA (if it has good quality)
   - Decaying average (or Kalman filter) methods to generate downscaling (DS) vectors
   - Downscaled forecasts
     - Based on bias corrected forecasts (#3), interpolated to 5km, applying DS vectors
   - Jointed development with ESRL/GSD through THORPEX
5. Final calibrated precipitation forecast with 2^{nd} moment adjustment (FY11-12)
   - Multi-model ensemble after bias correction
   - Hind-cast information to help extreme precipitation forecast (?)
   - Bayesian Process of Ensemble (BPE) (joined with GSD/ESRL through THORPEX)

PROBLEM - BIAS IN GFS MODEL QPF FORECASTS

Typical QPF bias in NWP forecasts:

Over-forecast small amounts
Under-forecast large amounts
Dependent on
- Model version
- Lead time
- Location



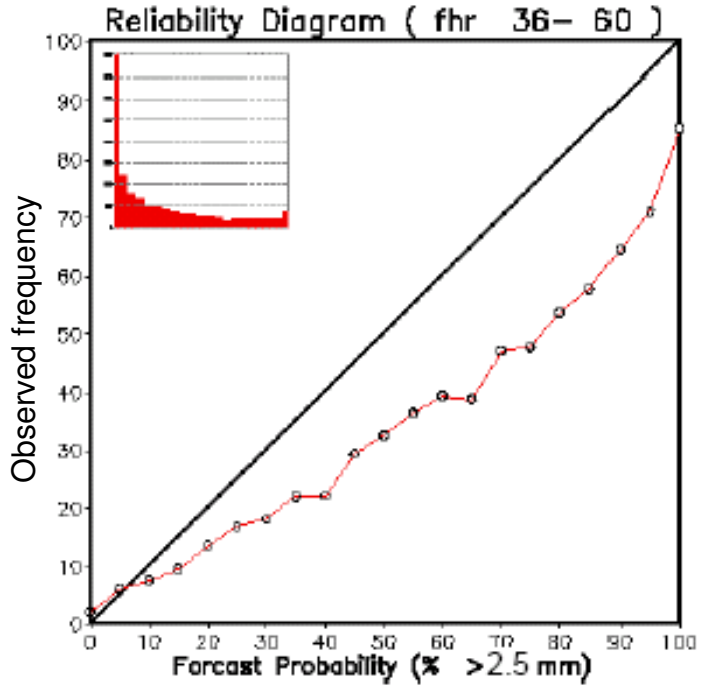
Model QPF bias contributes to bias in Ensemble-based PQPF forecasts:

Complicated effect on PQPF
QPF bias-removal should help PQPF

Bias in PQPF also affected by:

Inadequate spread in ensemble

NOT ADDRESSED IN THIS IMPLEMENTATION

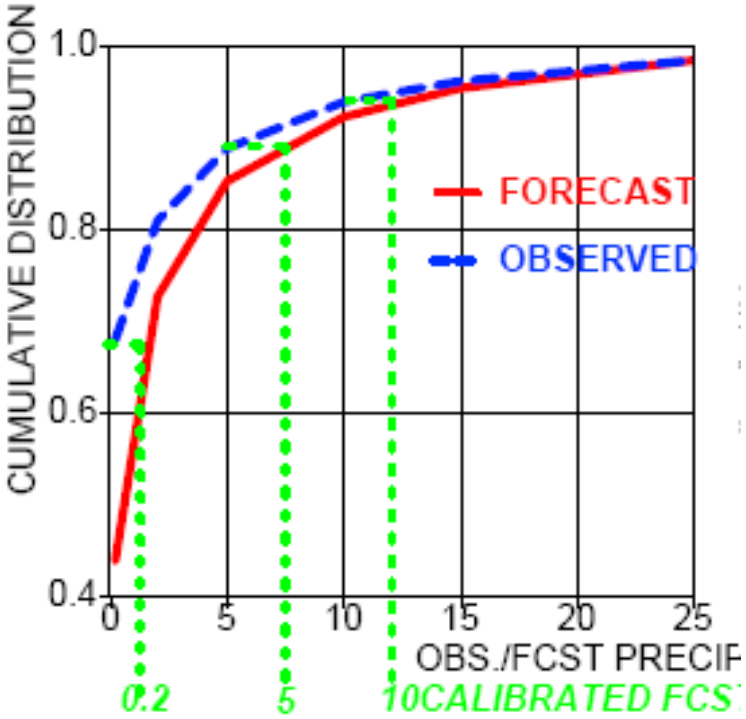


1. Background: QPF bias correction at NCEP

Implemented May 2004 (HPC and CPC endorsed)

METHOD

1) Construct cumulative frequency distributions for forecast QPF & corresponding observed values
2) For each forecast value, find the observed value that has the same frequency as forecast value
3) Re-label forecast value with corresponding observed value

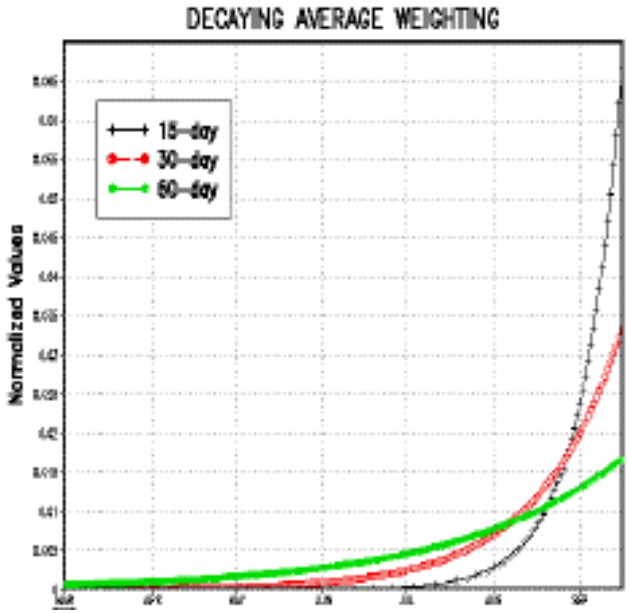


DETAILS

Observations used:
- US RFC rain-gage network
  - ~10,000 obs. analyzed over model grid

Adaptive method, training data accumulated over:
- Most recent ~30-day period – *Decaying averaging*
  - More weight on most recent data
- Continental US
- Linear inter/extrapolation

Corrections applied globally on model grid
- Correction is function of forecast value
- 2.5*2.5 degree spatial resolution
- Every 24 hour forecast interval



IMPLEMENTATION FACTS

Bias assessment - separately for:

- GFS and ensemble control fcsts
- Each lead time

Bias correction - applied on:

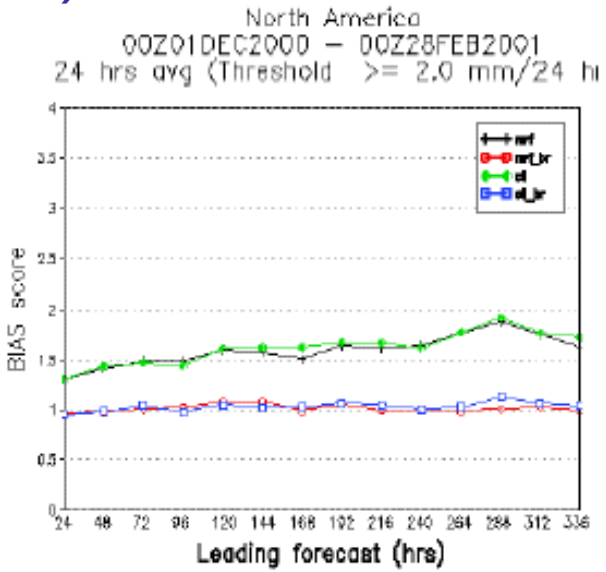
- Hi- & low resol. control forecasts
- All ensemble member fcsts
- At 0000 UTC initial time only
- 24-hr amounts only (00-00, 12-12Z)
- 2.5x2.5 lat/lon resolution

Bias-corrected QPF data – provided in:

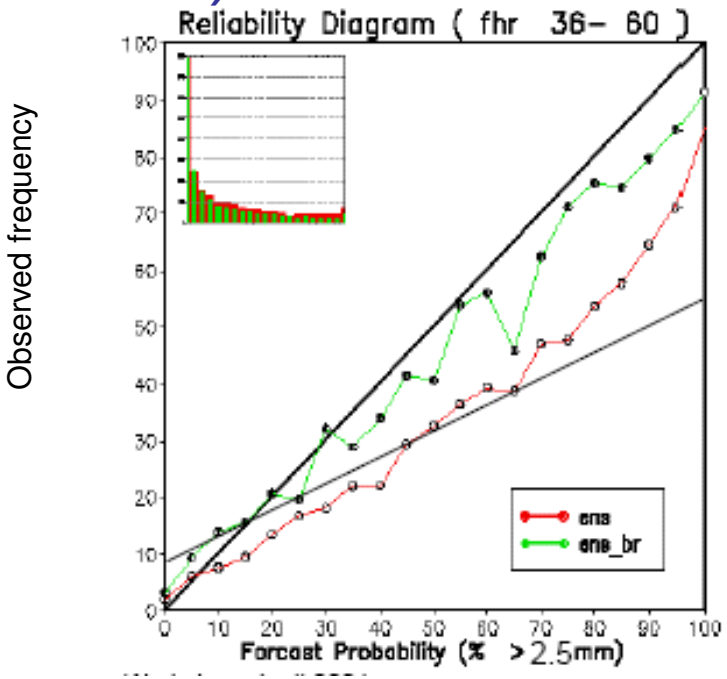
- enspost / ensstat files

OFF-LINE EVALUATION

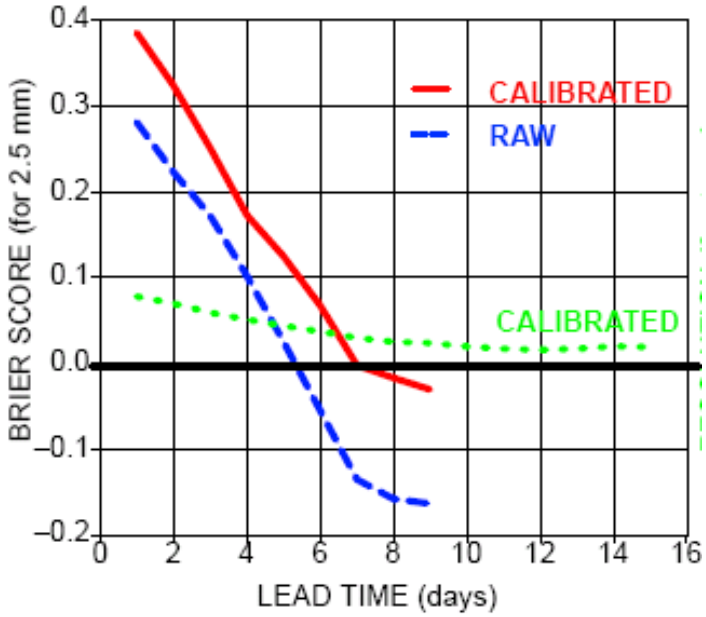
1) QPF bias much reduced



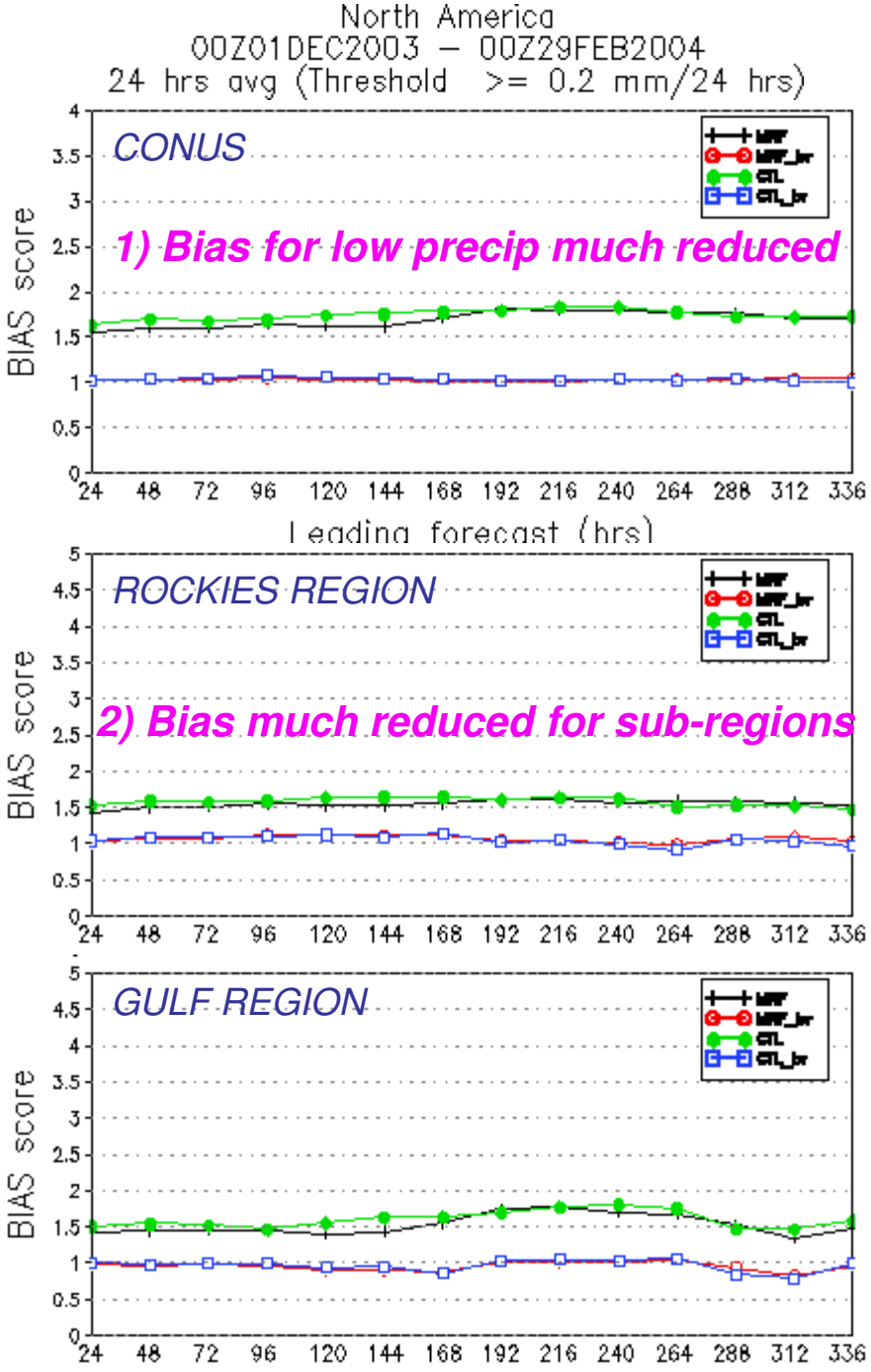
2) PQPF bias reduced

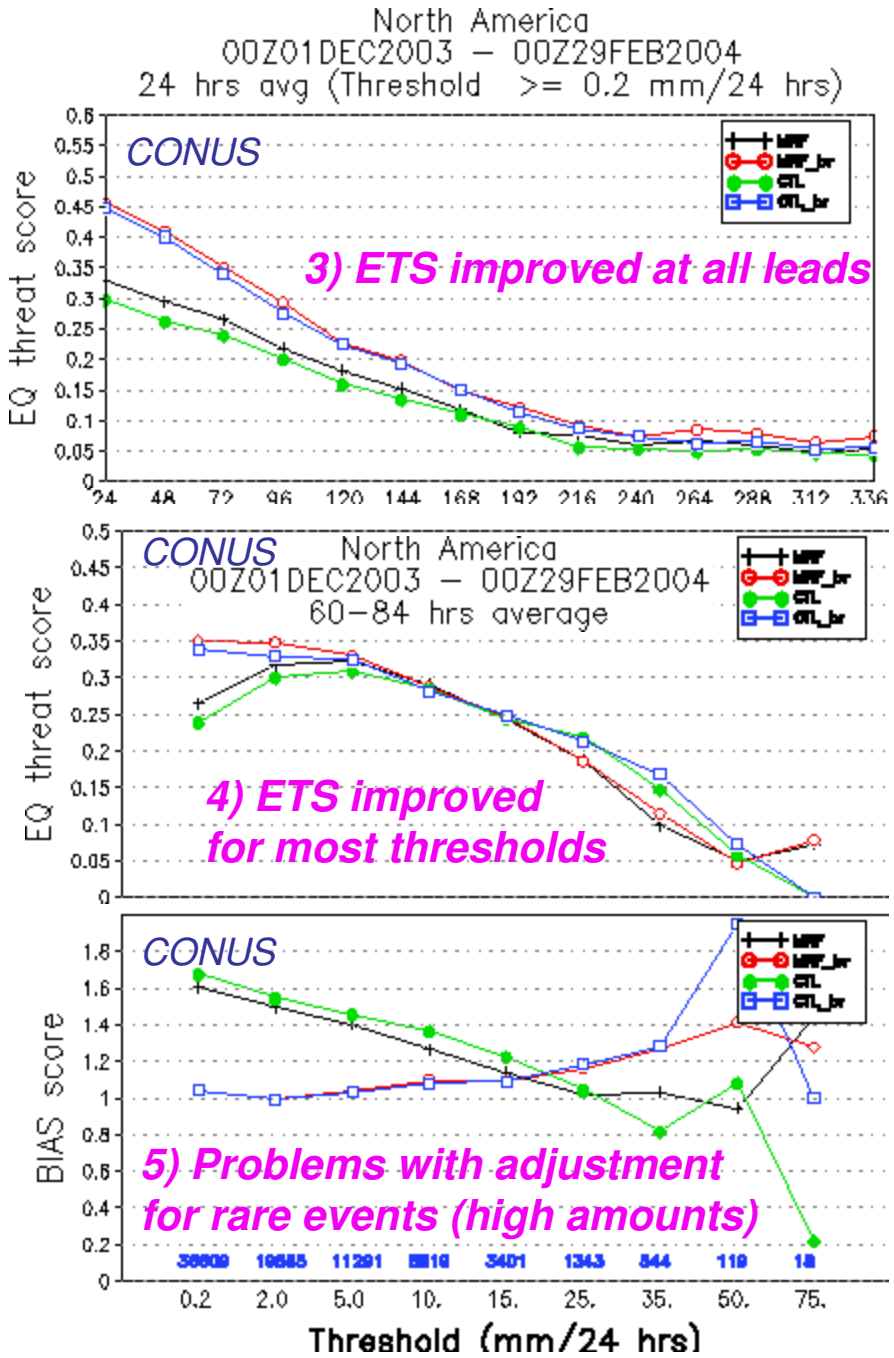


3) Much enhanced probabilistic skill



REAL-TIME PARALLEL TESTING RESULTS - EMC





2. Climatological Calibrated Precipitation Analysis (CCPA) – Q2FY10

- Why do we need another set of analysis
  - We need accurate precipitation analysis at
    - 5*5km (NDFD) spatial resolution
    - 6-hr (and 1-hr) temporal resolution
  - To satisfy various users
    - Have the reliabilities for climate study and hydrological applications (OHD)
    - Have the resolutions for short-range forecast applications (HPC)
  - To apply forecast calibration
    - Bias correction and downscaling
    - As inputs of Bayesian Processor of Ensemble (BPE)
    - Precipitation evaluation
- CCPA process details
  - Use CPC 30y 1/8deg daily, global land only
  - Use NCEP Stage IV (mosaicked QPE from multi-sensor RFCs), 4km HRAP grid, 6-hourly, ConUS only
  - To produce regression coefficients a and b
    - Offline calculation
    - Update every year to include latest information (or more frequently)
  - CCPA = a*Stage4 + b
  - Retain high-resolution information during interpolations, fill in the missing information by estimation
- Final available dataset
  - Main dataset is at 5km NDFD grid
  - Subsets include 1/8degree, 30km (for SREF), 0.5degree and 1.0degree

Two precipitation datasets

1. CPC Unified Precipitation Analysis
   - Back to 2000 (eventually back to 1979, then 1948)
   - ⅛° spatial resolution
   - Daily
   - Global land
2. NCEP Stage IV analysis
   - Mosaicked QPE from multi-sensor RFCs
   - Back to January 2002
   - ~4km HARP grid (spatial resolution)
   - 6-hourly
   - ConUS

- RMORPH
  - Future use for global post-processing

Combining Information

- **CPC:**
  - ✓ More confidence in long term statistics of CPC dataset
    a. Uniform QC across entire domain
    b. Gauge-based
  - ✗ Too low resolution for downscaling
- **NCEP Stage IV:**
  - ✓ High resolution (close to NDFD) → better representation of fine scale temporal and spatial variability
  - ✗ Non-uniform QC (different RFCs have different methods)
  - ✗ Each RFC may make their own adjustments before mosaicking
- *Solution*: adjust NCEP Stage IV grids so their climatology is consistent with the CPC dataset
  - ✓ Have the reliability of the CPC dataset, with the high spatial and temporal resolution of the RFC dataset

Establish Statistical Relationship

1. Match resolutions
   a. Accumulate NCEP Stage IV over 24 hours
   b. Interpolate to ⅛° (copygb w/ volume preservation)
2. Collect precip samples
   a. For each day of the year and at each grid point, collect all precip within 60 day window centered around that day, over all 7 years (max ~420 data points)
3. Linear regression
   a. $CCPA = a \cdot Stage4 + b$
   b. Use only data points with $Stage4 > 0$

- End Result
  – Linear relationship (a & b) on ⅛° grid for each day of the year

3. Upgrade QPF bias correction from #1 – Q2FY10

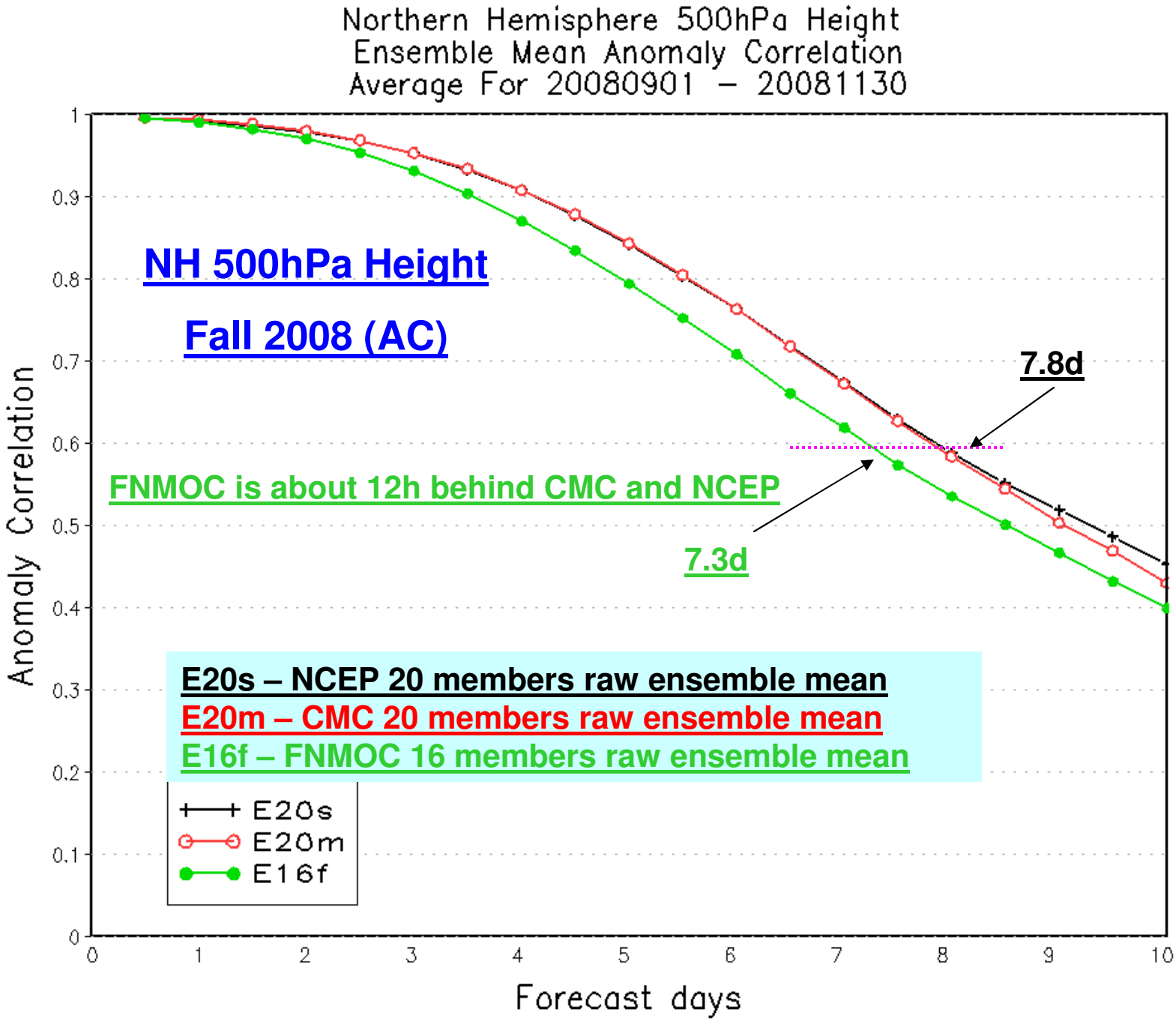
- Upgrade from May 2004's implementation
  - Important changes
    - Calculate forecast CDF from 1.0d resolution
      - For GFS, and ensemble control
      - Every 24-hr, out to 16 days
      - Every 6-hr, out to 16 days
      - For SREF and NAM
    - Calculate observation (truth) CDF from gauge
      - For 24-hr accumulation, 12UTC-12UTC
    - Calculate observation (truth) CDF from CCPA
      - For 6-hr accumulation
    - Decaying (or Kaman Filter) average by use weight=0.02
    - Use CDF from gauge to calibrate CDF from CCPA
  - Applications
    - Adjust GFS forecast
    - Adjust GEFS each members include control
    - For every 6-hr forecast out to 16 days
    - The same process for SREF and NAM forecast
- Main products
  - Bias corrected precipitation forecast at 1*1 degree resolution, every 6 hours, out to 16 days for GFS, ensemble control and ensemble members
  - Dual-resolution probabilistic forecast: PQPF after bias correction
    - For selected threats (>0.2, 2.0, 5.0, 10.0, 25.0, 50.0mm and etc…)

4. Statistical downscaling to 5km – Q4FY10

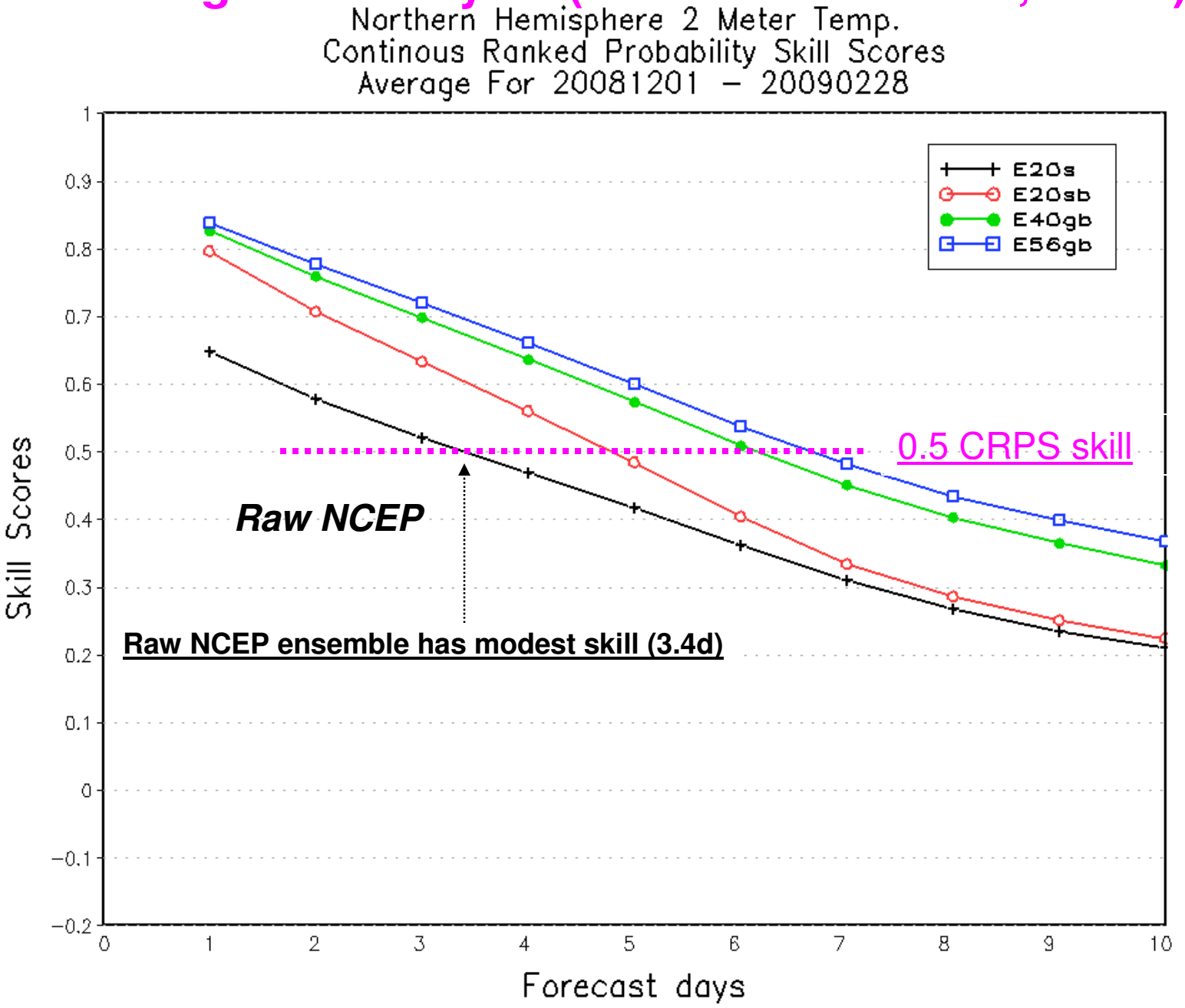
- Use first 6 hours forecast (1*1 degree) as model analysis
  - Interpolate to 5km NDFD grid (copygb w/ volume preservation)
  - Calculate CDF (decaying, high weighting – 0.1)
- Use CCPA as a proxy truth
  - Calculate CDF (decaying, high weighting – 0.1)
- Produce downscaling vector
  - Based on above two CDFs
  - For each defined region (RFC), not grid point
    - May test for neighborhood consideration
- Final process
  - Interpolate 1*1 degree bias corrected forecast to 5km resolution
  - Apply downscaling vectors
    - Mainly frequency matching the forecast CDF to true CDF
  - Totally four vectors (every 6-hour each)
  - Produce downscaled forecast at 5KM
- Introduce pseudo-precipitation (option)
  - Jointly with ESRL/GSD

5. Final calibrated forecast with 2nd moment adjustment – FY11-12

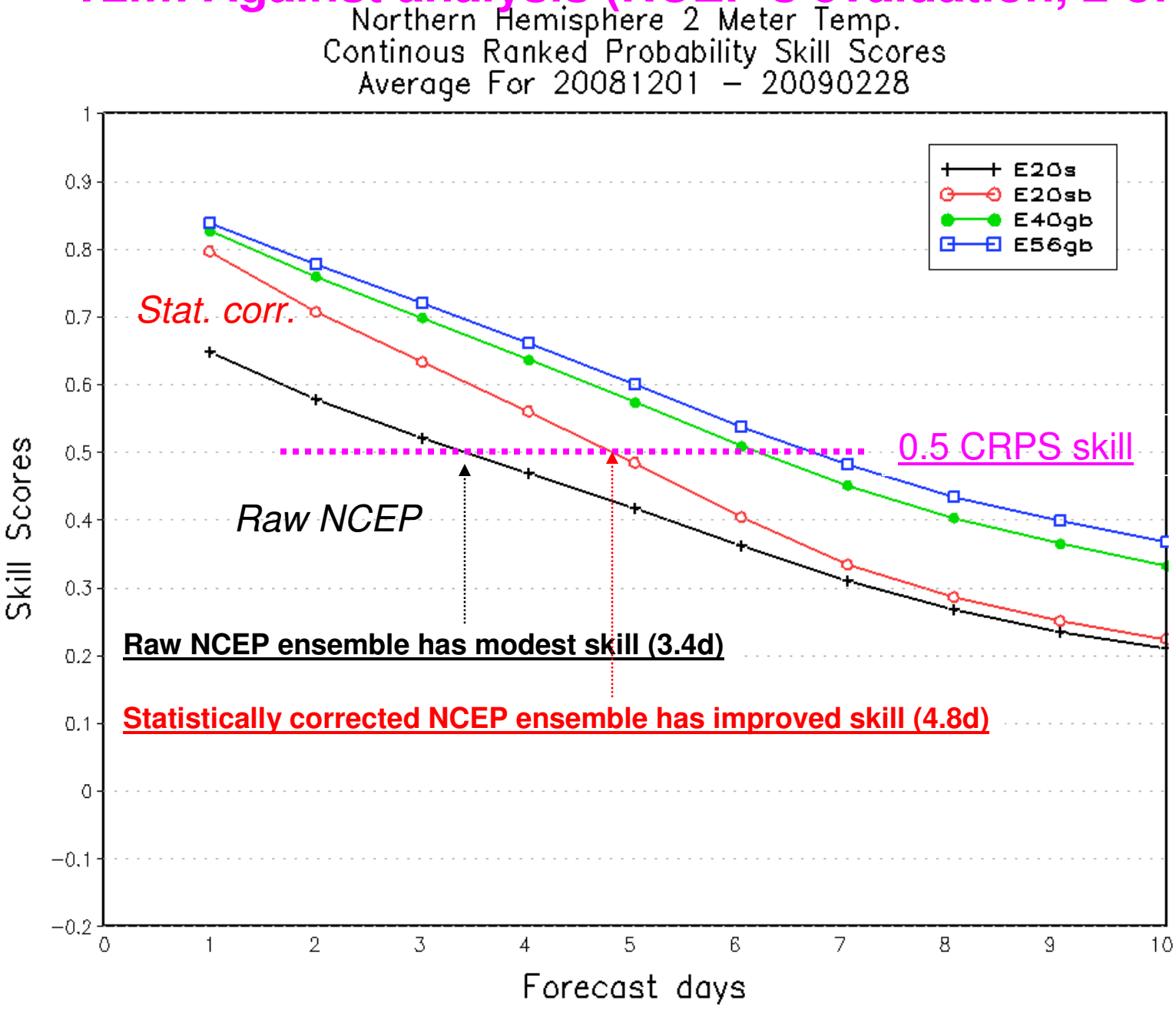
- Multi-model ensembles (MME)
  - Current NAEFS (NCEP+CMC) ensemble with bias correction
    - NAEFS will expand to add FNMOC ensemble
  - Possible to combine with ECMWF ensembles with bias correction
- BPE (Bayesian processor for ensemble)
  - Joined developed with ESRL/GSD
- Other methods
  - Will adopted if it works


Northern Hemisphere 500hPa Height
Ensemble Mean Anomaly Correlation
Average For 20080901 – 20081130
NH 500hPa Height
Fall 2008 (AC)
7.8d
FNMOC is about 12h behind CMC and NCEP
7.3d
E20s – NCEP 20 members raw ensemble mean
E20m – CMC 20 members raw ensemble mean
E16f – FNMOC 16 members raw ensemble mean
E20s
E20m
E16f
Anomaly Correlation
Forecast days
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1
2
3
4
5
6
7
8
9
10

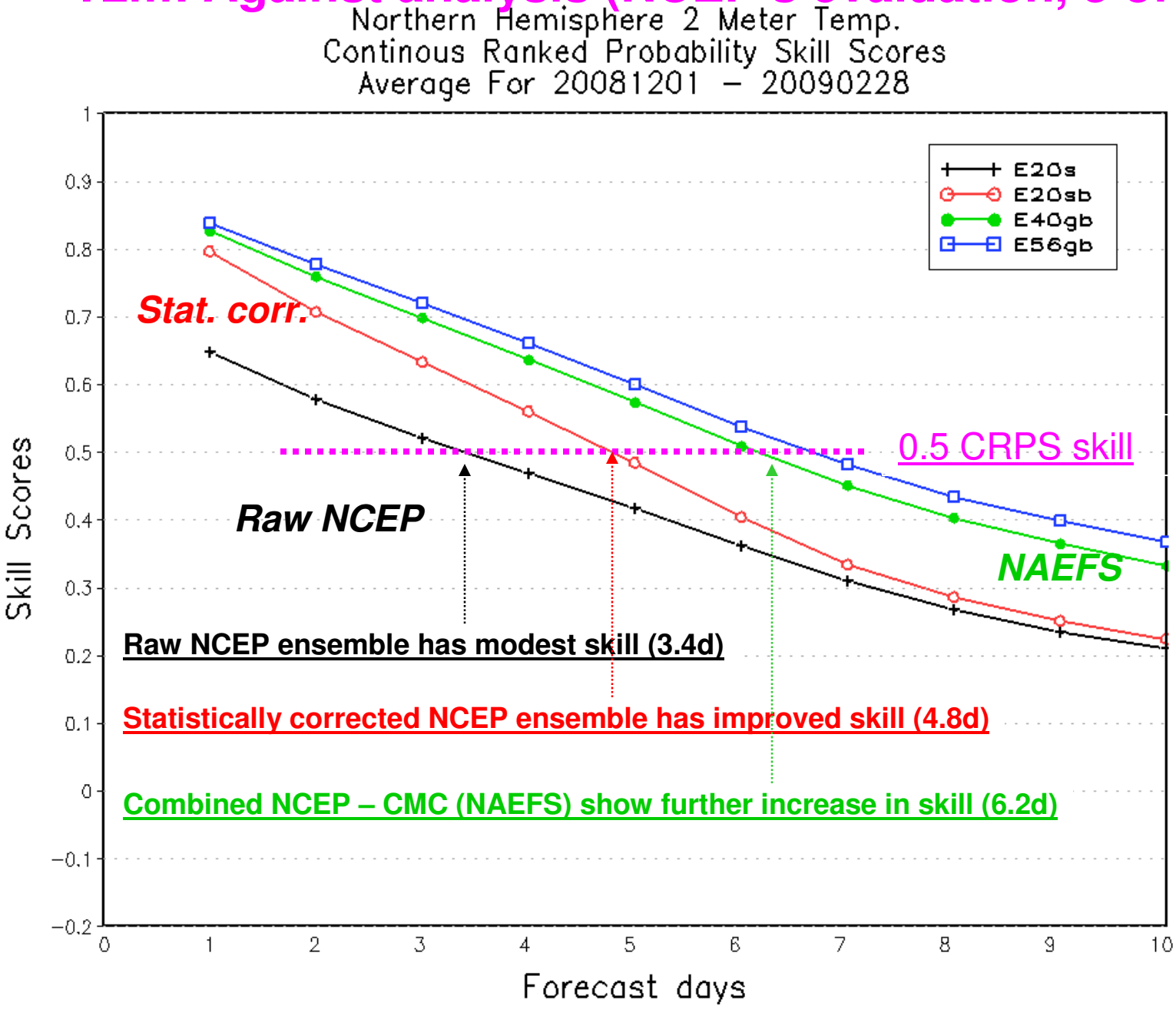
Value-added by including FNMOC ensemble into NAEFS
T2m: Against analysis (NCEP's evaluation, 1 of 4)



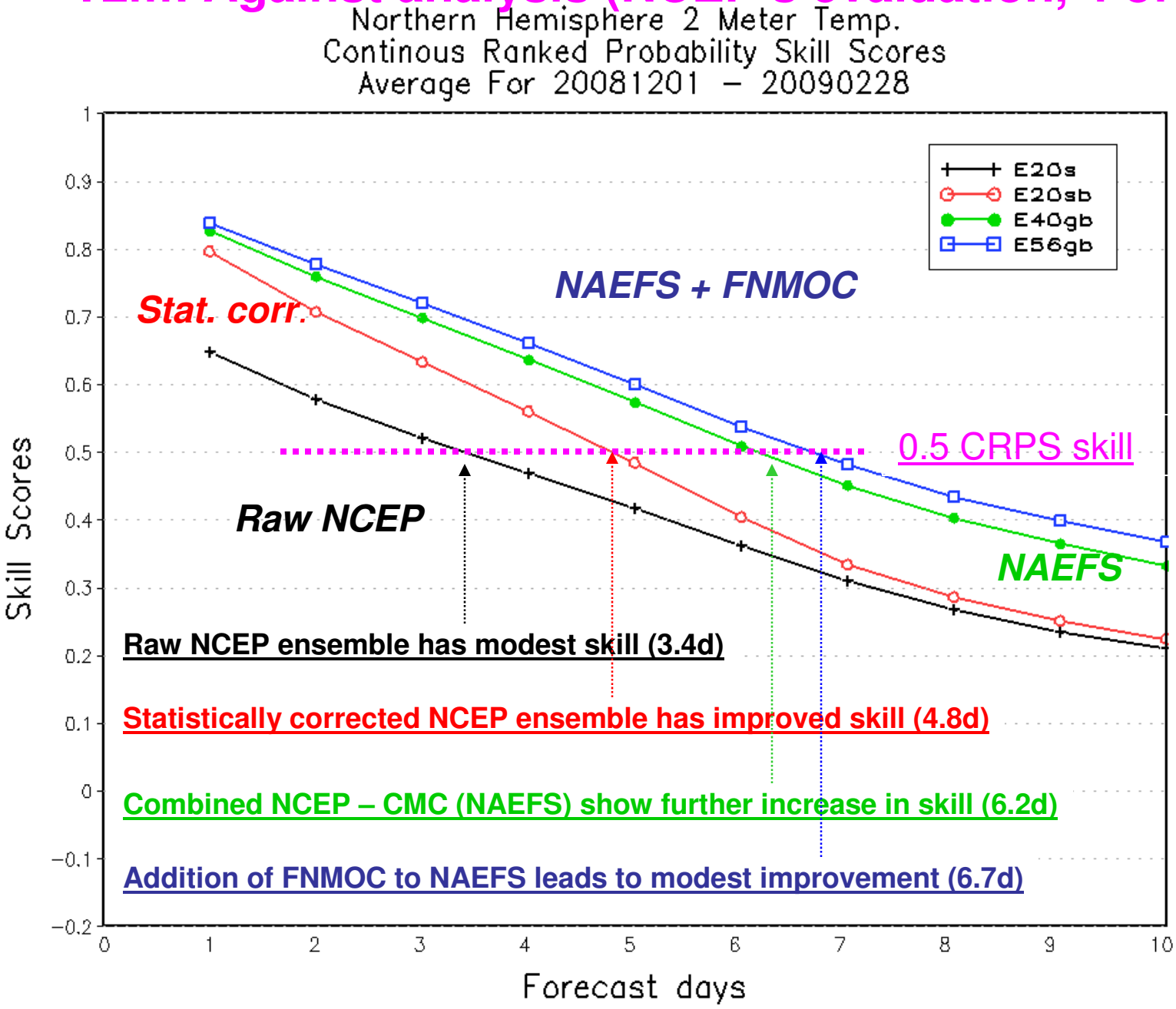
Value-added by including FNMOC ensemble into NAEFS
T2m: Against analysis (NCEP's evaluation, 2 of 4)

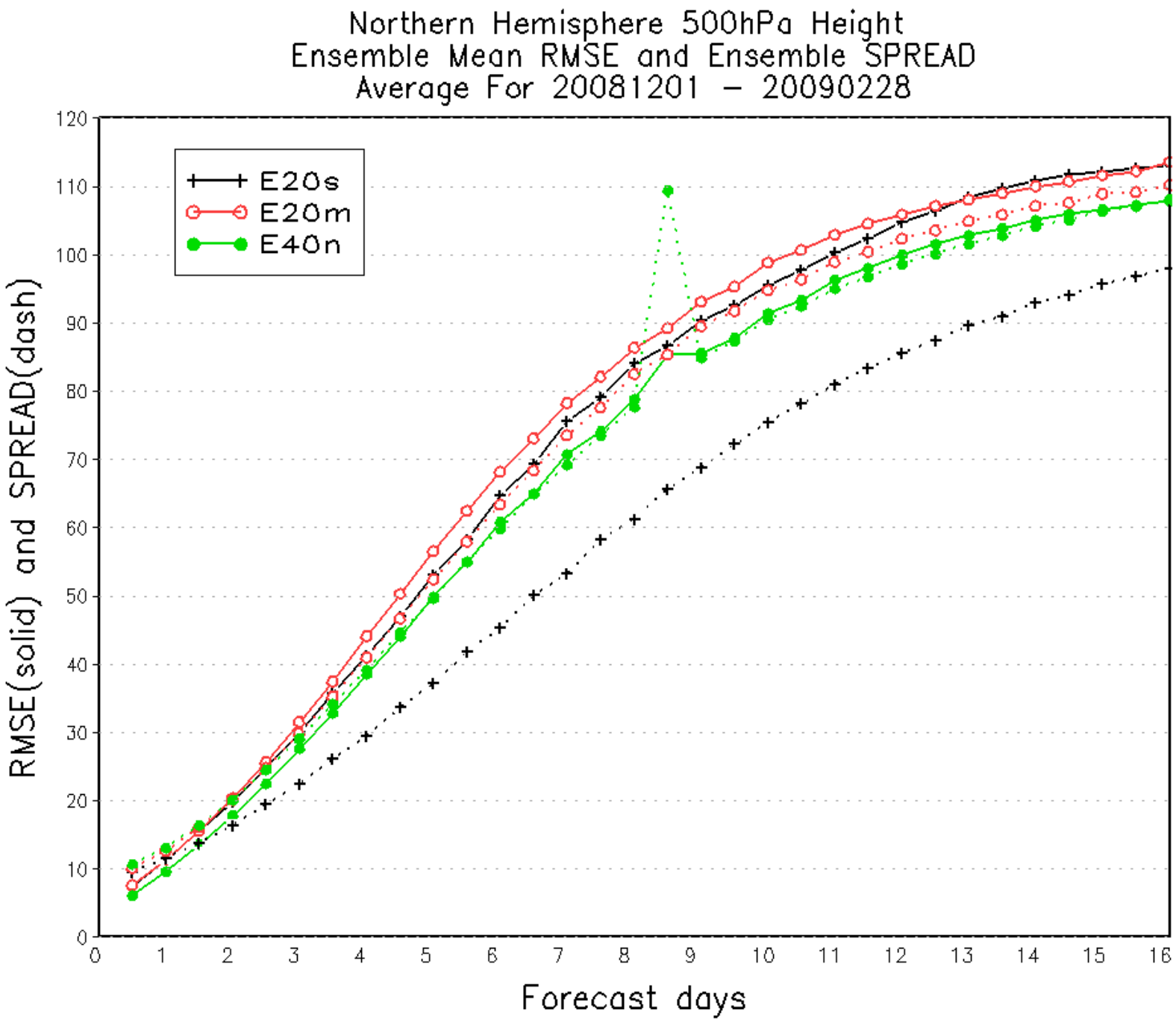


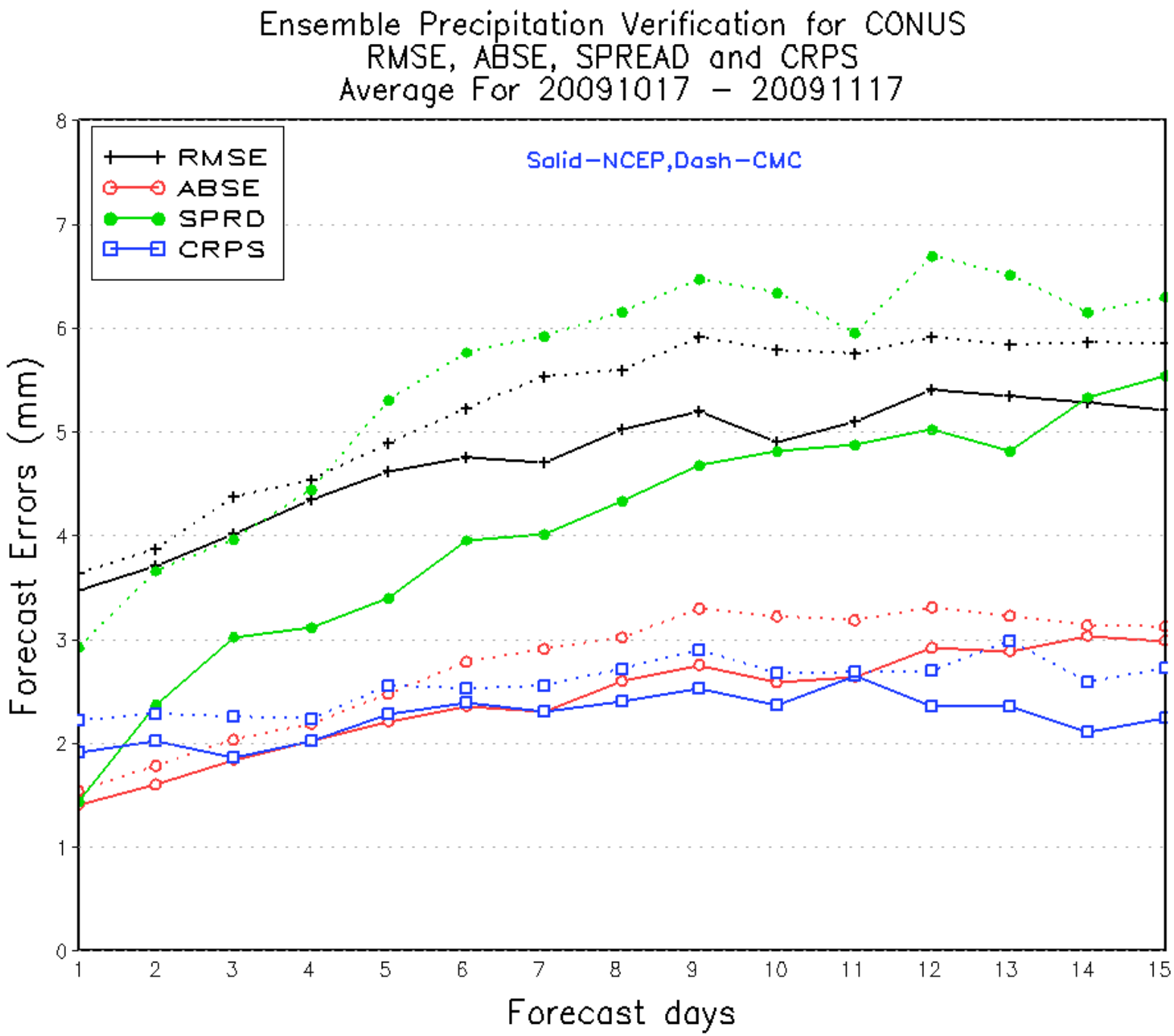
Value-added by including FNMOC ensemble into NAEFS
T2m: Against analysis (NCEP's evaluation, 3 of 4)



Value-added by including FNMOC ensemble into NAEFS
T2m: Against analysis (NCEP's evaluation, 4 of 4)




Northern Hemisphere 500hPa Height
Ensemble Mean RMSE and Ensemble SPREAD
Average For 20081201 – 20090228
E20s
E20m
E40n
RMSE(solid) and SPREAD(dash)
Forecast days
0
10
20
30
40
50
60
70
80
90
100
110
120
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16


Ensemble Precipitation Verification for CONUS
RMSE, ABSE, SPREAD and CRPS
Average For 20091017 - 20091117
RMSE
ABSE
SPRD
CRPS
Solid-NCEP,Dash-CMC
Forecast Errors (mm)
Forecast days
0
1
2
3
4
5
6
7
8
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Background!!!

Why do we need another dataset?

- Want an accurate, 5x5 km (NDFD), 6-hourly precip grid

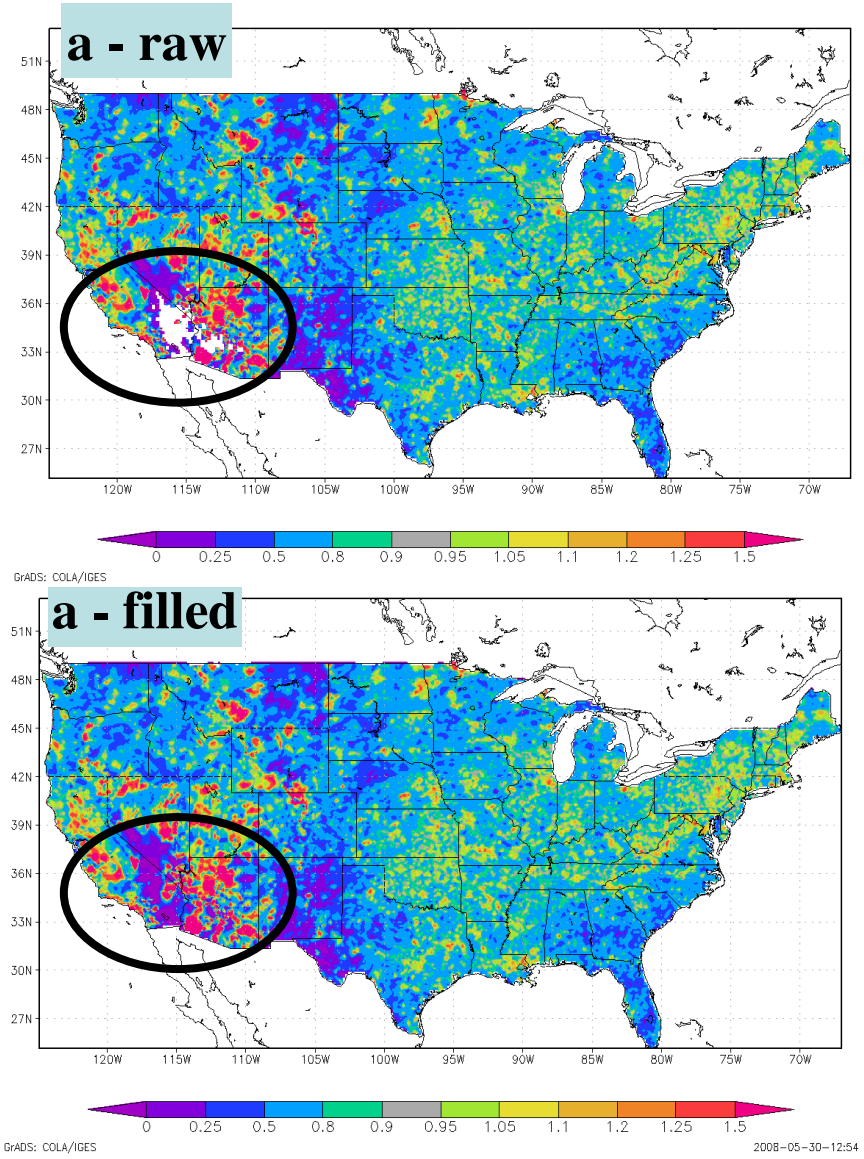
1. Input to Bayesian Processor of Ensemble (BPE)
2. Downscale NAEFS precipitation forecasts to NDFD
3. Verify NAEFS precipitation forecasts

- **Note: This effort has limitations, as it was developed to simply combine existing datasets. Much more work will be needed for a more comprehensive approach, but this is out of the scope of this work**

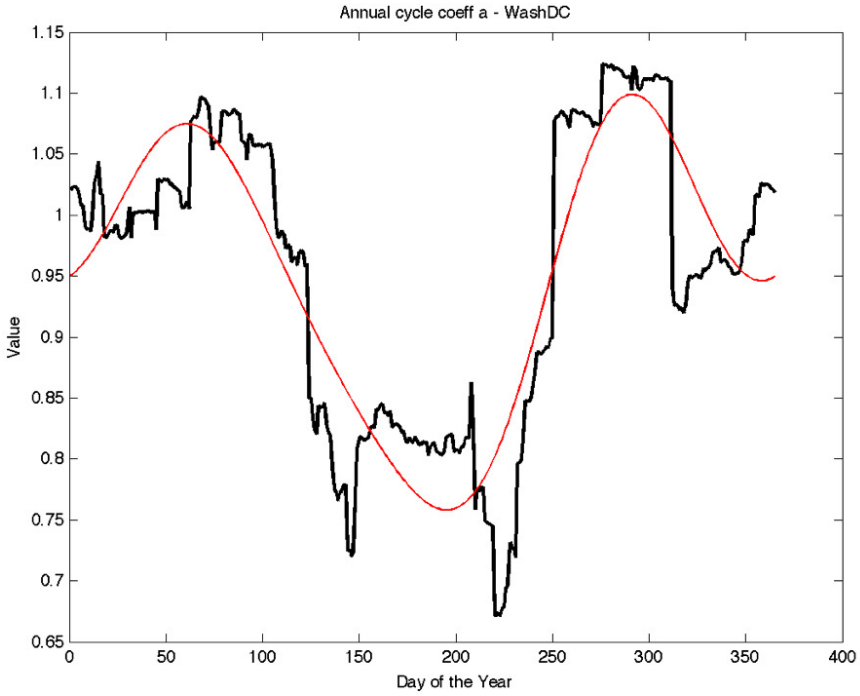
Courtesy of Mike Charles and Zoltan Toth

Fill Missing Data and Smooth

Bilinearly interpolate missing values



Fourier transform (3 harmonics) over 365 days to smooth temporally but keep annual signal



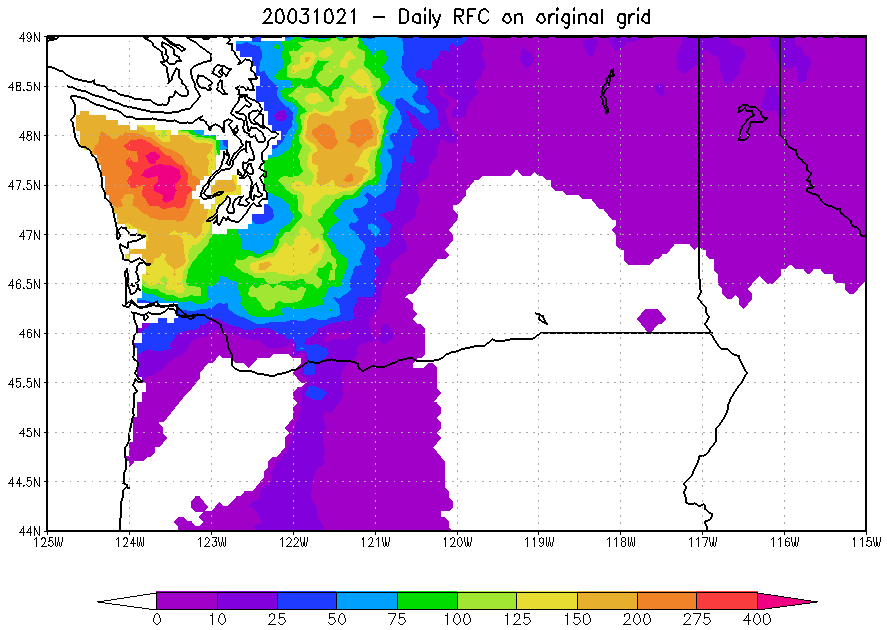
Repeat at each gridpoint and replace all daily spatial grids

Adjust Entire Dataset

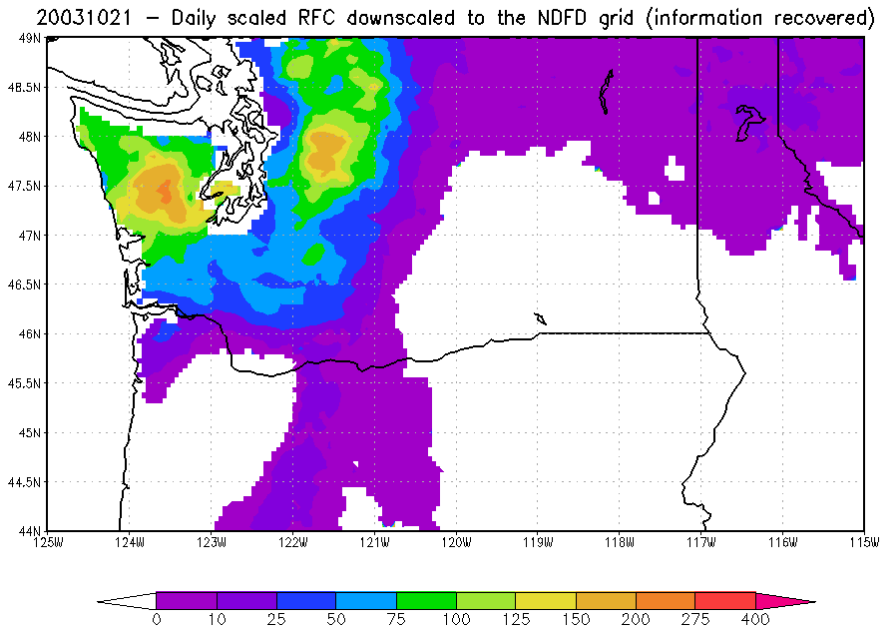
$$CCPA = a \cdot Stage4 + b$$

- Transform linearly each daily ⅛° Stage4 grid over 7 years:
  - Multiply by *a* then add *b* to get *CCPA*

Stage4

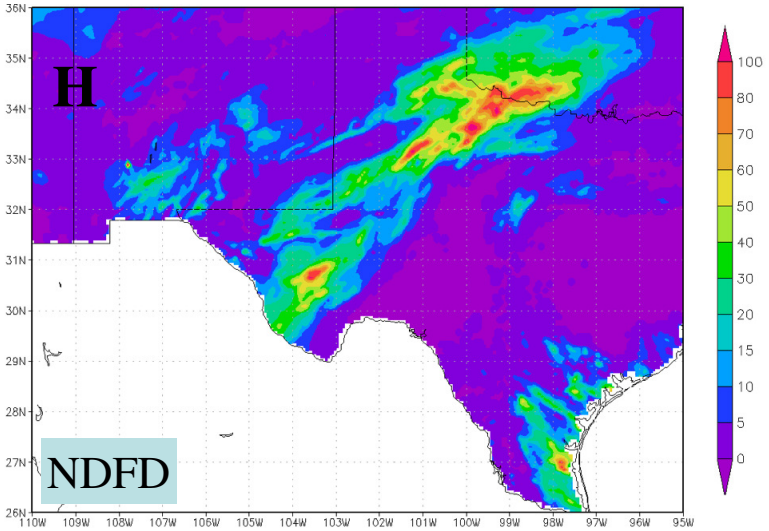


CCPA



Recovering Original Stage4 Resolutions

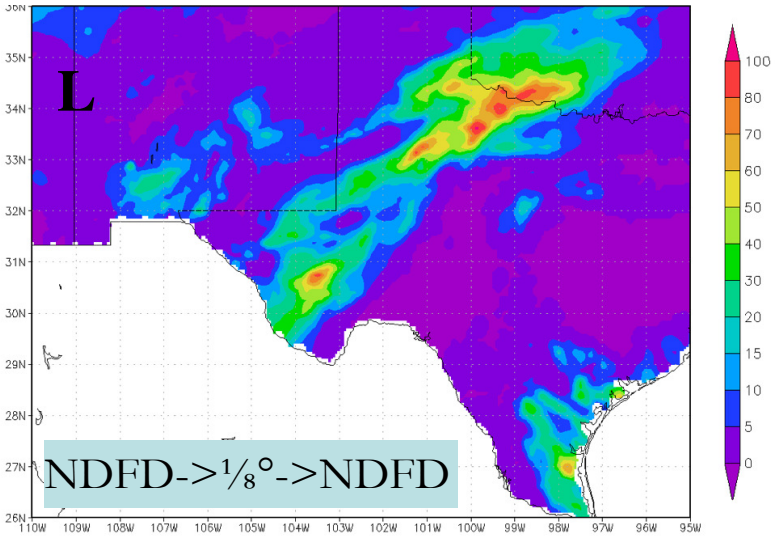
Spatial Disaggregation

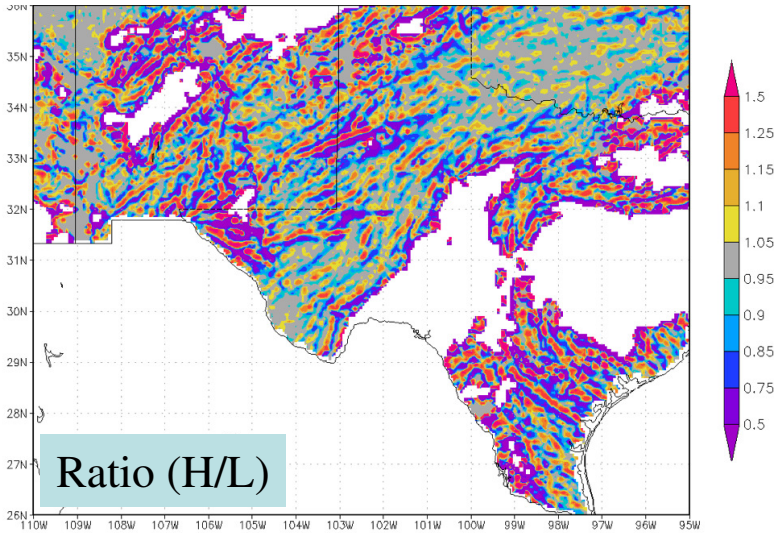


- Information is lost between H and L
- How much information?
  - Take ratio H/L (below)
  - This ratio can be used to put high resolution information back into Stage4*

1. Interpolate Stage4* to NDFD
2. Multiply by H/L

- End with Stage4* at NDFD resolution.
- Spatial information recovered from $Stage4_{orig}$





Recovering Original Stage4 Resolutions

Temporal Disaggregation

1. Determine percentage of daily total precipitation in each 6-hour period in $Stage4_{orig}$

2. Divide 24 hour Stage4* into four 6-hour precip amounts using the percentages from $Stage4_{orig}$

Percent of daily total in each 6-hourly period